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ON THE USE OF ARTIFICIAL RESPIRATION AND TRANSFUSION AS A MEANS OF PRESERVING LIFE.

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IN his admirable *Lessons in Physiology*, Huxley says that "the brain, the lungs, and the heart, have been fancifully termed the tripod of life; but, in ultimate analysis, life has but two legs to stand upon, the lungs and the heart, for death through the brain is always the effect of the secondary action of the injury to that organ upon the lungs or the heart." This conclusion is founded on the experiments of many observers, among the most interesting of which are those of the Abbé Fontana and Legallois.* The former found that the brain was not necessary to life; for he could cut off the heads of rabbits and guinea-pigs, and yet keep their bodies alive by connecting a pair of bellows with the trachea, and keeping up artificial respiration. As he himself says, an animal can live quite well without a head: artificial respiration and the circulation of the humours in the various parts are quite sufficient. The headless trunks evidenced their vitality by displaying sensitiveness to impressions, and executing what the abbé considered to be voluntary movements, but which we would now term simply reflex actions. Legallois went even further than Fontana; for, not content with cutting off the rabbit's head, he tied the aorta and vena cava, and then cut away the whole of the posterior part of the body, leaving only the headless thorax. This fragment of the body, mutilated as it was, still remained alive; the fore paws showed sensibility when irritated; and the thorax twisted when the skin over it was pinched, or

* Fontana, *Traité sur le vénin de la vipère, sur les poisons Américains, sur le laurier cerise, et sur quelques autres poisons végétaux.* Florence, 1781, tome i, page 317.—Legallois, *Expériences sur le principe de la vie.* Paris, 1830, tome i, p. 130.

more distinctly still if the lower end of the spinal cord were touched. Even when the experiment was carried farther, and the whole of the cervical with part of the dorsal spinal cord was destroyed, evidences of life could be observed in the posterior two-thirds of the thorax. These experiments demonstrated beyond doubt that, if the lungs and heart could perform their functions with any other fragment of the body as they do with the thorax, it might be kept alive. As Legallois himself says, "if the place of the heart could be supplied by a sort of injection, and if at the same time a supply of arterial blood, either natural or artificial, if such a formation of blood were possible, could be obtained, life might be maintained indefinitely in any fragment of the body whatever; and consequently a decapitated head might be kept alive and in possession of all the faculties pertaining to the brain. Not only could life be maintained in this manner, either in the head or in any other isolated part of an animal's body, but it might be recalled after its entire extinction; it might even be recalled to the whole body, and a veritable resurrection, in every sense of the word, might be effected." Perhaps it may seem that the success of his experiments rendered Legallois too sanguine; but his anticipations have already in great part been fulfilled, and a decapitated head has been partially at least restored to life by M. Brown-Séquard. His experiment, as related by M. Vulpian,* consisted in cutting off the head of a dog immediately after it had been killed, and connecting the carotid and vertebral arteries with an apparatus for artificial circulation. After eight or ten minutes had elapsed, and all signs of excitability in the medulla oblongata and the rest of the encephalon had been gone for several minutes, defibrinated and arterialised blood was injected simultaneously into the vertebrals and carotids. In a few seconds, signs of life began to appear, and the muscles of the eyes, in fine, acted in such a way as seemed to prove that the cerebral functions were re-established.

Hardly less astonishing than Brown-Séquard's experiments are those of Preyer,† who has succeeded in restoring their vital properties to a frog's muscles after they have been brought into the state of rigor mortis by dipping them into warm water. This condition depends on coagulation of the muscular substance or myosin; and circulation of blood alone through muscles in this state is of no use, for it cannot soften the hardened myosin. Something more is, therefore, necessary. Coagu-

* *Revue de Cours Scientifiques*, 1864-5, tome ii, p. 217.
† *Centralblatt für die Med. Wissenchaft.*, 1864, p. 769.

lated myosin is soluble in a solution of common salt; but, though a muscle dipped in such a solution may lose its hardness and again become soft and pliable, it does not regain its vitality. By combining the two methods, however, the difficulty has been overcome; and, by first dipping the rigid muscle in a solution of salt, and then allowing blood to stream through it, Preyer has had the satisfaction of seeing frogs jump and swim by the aid of muscles which had been almost as hard and stiff as a piece of wood only a short while before.

Nor are nerves and muscles the only parts which can be kept alive by artificial circulation. Glands also preserve their vitality; and Ludwig and his pupils,* by maintaining artificial circulation in them, have succeeded in making livers secrete bile, and lungs excrete carbonic acid, for hours after they have been excised from the body.

More examples might be given; but the above are sufficient to show the power of artificial circulation to keep any part of the body alive after the death of the rest. The converse of this is also true; and, if blood be prevented from circulating through any part of the body, that part will die, although the rest may remain healthy. So generally known is this, that no one ever thinks of tying a bandage so tightly as to stop the circulation, and leaving it thus, as he well knows that death, or, as we usually term it, mortification, of the ligatured part would be the result. It is easy for any one, indeed, to observe for himself the destructive effects of want of blood and the vivifying power of renewed circulation, by repeating the experiment devised by the Danish physiologist Steno or Stenson more than two hundred years ago. A gentle steady pressure with the thumb on the abdominal aorta of a rabbit, so as to stop the circulation for a couple of minutes, is all that is necessary to produce complete paralysis of the hind legs of the animal; and a few minutes more of renewed circulation suffice to restore them to their normal state. It might almost seem that the tripod of life had been reduced to one leg—viz., a circulating apparatus or heart; but this is not the case, for it must be remembered that the blood which circulates must be oxygenated or arterial; and if, as in the case of artificial circulation, there be no lungs to effect its oxygenation, their place must be supplied by agitation with air, though this is at best but a poor substitute. Indeed, it is rather because the blood carries oxygen than nutriment to the tissues, that arrest of circulation causes them to die so speedily; for Kronecker found† that, after

* Ludwig's *Arbeiten*, 1868, p. 113, and 1870, 38.
† Ludwig's *Arbeiten*, 1877, p. 182.

he had exhausted the muscles of a frog by constant irritation, he could restore their contractility by passing through their vessels a solution of permanganate of potash, which, like the blood, could supply them with oxygen, although it could yield them no nourishment.

The body is made up of a number of parts; and, if the heart stop, the circulation ceases; or, if the lungs fail to perform their duty, so that the circulating blood is no longer arterialised, all the parts, and therefore the whole body, will die. But the parts will not all die at the same time; and this is a point of great practical importance. The brain and spinal cord generally die first, and the heart may be pulsating as regularly as ever when all respiratory movements have ceased, and no irritation, however intense, will evoke the faintest indication of consciousness, or excite the slightest reflex action. The muscles retain their irritability still longer than the heart; and they continue to possess their power of contraction, and the lungs their ability to oxygenate the blood, even after the cardiac pulsations have entirely ceased. Here, then, we come to the third leg of the tripod of life—viz., the brain—for want of which the other two cannot stand. The whole body, in fact, may be, and often is, alive, with the exception of the nervous centres. The heart is alive; the lungs are alive; but the brain is dead, and, without it, the respiratory muscles will not work. The want of oxygen weakens the heart; it gradually stops; and then the other parts of the body die, each in its turn. But, if the respiration can only be kept up artificially, the heart will go on beating; the circulation of arterial blood through the brain may gradually restore its power; the rhythmical movements of natural respiration will again begin, and the life of the animal once more be securely established. This is no mere fanciful dream, but sober fact, as the successful efforts of the Humane Society to resuscitate persons apparently dead abundantly prove. It has, moreover, been lately demonstrated in a striking manner in some experiments of Schiff.* These were made for the purpose of ascertaining what the use of artificial respiration would be in concussion or compression of the brain, or in cases of apoplexy where a clot has formed in the medulla oblongata, and, by pressing upon that part of it which presides over the innervation of the muscles of respiration, has put a stop to these movements. In order to imitate the effect of an apoplectic extravasation, Schiff anæsthetised a dog with ether; and, after exposing the medulla oblongata, destroyed a considerable

* *La Nizione*, 1872, No. 102.

part of it with a scalpel or sound, though he always left one lateral column at least intact. Immediately after the injury, the respiration ceased, the tongue became swollen and livid, convulsions occurred, and the animal appeared to be dying. The heart became weaker and weaker; but, when it had almost ceased to beat, artificial respiration was begun. Very shortly the pulsations regained their normal strength, and the death-like lividity of the tongue gave place to the rosy hue of health. After respiration had been kept up for a few hours, it was discontinued; and then, if the injury to the medulla had not been too great, spontaneous respiratory movements commenced, but they were still feeble. They became much stronger if artificial respiration were again renewed for half an hour longer—strong enough, indeed, to keep the animal alive without any artificial assistance. It is true that, when the lesion had destroyed the one side of the medulla, only one-half of the thorax took part in the respiratory movements; but this was in many cases quite sufficient for the wants of the animal. In the only case in which Schiff attempted to keep the animal alive permanently, he was perfectly successful. The beneficial effects of artificial respiration were equally encouraging when natural respiration was arrested by compression of the brain through the injection of tepid water under high pressure into the cranial cavity. From these experiments, it is evident that we may hope for the best results from the use of artificial respiration in some of those cases of apoplexy where an extravasation almost instantly arrests the respiratory movements, either directly by destroying a part of the medulla, or indirectly by causing compression of the brain. It may be thought that there is a considerable difference between the compression produced by the injection of tepid water and that which is due to an extravasation of blood, inasmuch as the water will be rapidly absorbed, while the blood will not. To a great extent this is true; and we can hardly expect very much good from artificial respiration in cases of apoplexy where the clot is large and the affection of the respiration is gradual. In those cases, however, where a small extravasation only has taken place in or near the medulla, the respiratory movements are abolished, just as in Schiff's experiments, by what may be termed the shock, although the medulla could carry on respiration well enough if time were given it to recover from the immediate effects of the injury. The employment of artificial respiration for a few hours would give the time required.

In another class of cases—that of poisoning by woorara, hydro-

cyanic acid, etc.—artificial respiration is invaluable. In his *Travels*,* Waterton tells a melancholy story of a poor Indian who, when shooting at a monkey sitting in a tree straight above him, was wounded near the elbow by his own arrow as it fell down. He immediately became convinced that it was all over with him. "I shall never," said he to his companion in a faltering voice, and looking at his bow as he said it; "I shall never bend this bow again." Having said this, he took off the little bamboo poison-box which hung across his shoulder, and putting it, together with his bow and arrows, on the ground, he laid himself down beside them, bade his companion farewell, and never spoke again.

It is not true, as some persons formerly supposed, that the minutest quantity of woorara in the blood is sufficient to cause death. It is a very powerful poison, certainly; but there is a limit to its virulence; and, if there be too little of it in the blood, it will have no action. On this account, it is not usually poisonous when swallowed; for it is excreted by the kidneys as quickly as it is absorbed from the stomach, and so there is never enough in the blood at any one time to produce any effect whatever on the body. The result is very different, however, when the kidneys are prevented from acting by ligatures applied to the ureters. Then the poison, which is gradually absorbed from the stomach, goes on accumulating in the blood; and by and by, when it has reached the necessary amount, it produces exactly the same effects as if it had been injected directly into the veins. When the poison is applied to a wound, it is usually absorbed more quickly than the kidneys can excrete it, and so poisoning occurs. But, if a ligature be applied above the wound so as nearly to stop the circulation, the absorption of the poison may be hindered so much that it is not taken up from the wound any faster than the kidneys can excrete it. Thus the whole of it may be got rid of, without its ever being able to produce any toxic effects whatever. If the circulation be allowed to go on at all in the wounded part, it is rather difficult to regulate it exactly enough to ensure that too much poison shall not be absorbed at once. It is, therefore, better to apply the ligature so tightly as to stop the circulation altogether, and only remove it occasionally for a few seconds at a time. In this way, it is easy to control the absorption of the poison by removing the ligature with more or less frequency, and leaving it off for a longer or shorter period, as seems advisable. But it is not by regulating the absorption of woorara only that we are able to

* *Travels in South America*, 1825, p. 71.

prevent its toxic action. Even when a large quantity is circulating in the blood, and the animal seems perfectly dead, recovery is still possible.

The woorara, curare, or ticunas poison—for it has all these names, and several more—has little or no action on either the brain or the muscles; but, as Bernard has shown, it paralyses the motor nerves; and so the rhythmical nervous impulses which the medulla usually sends to the muscles of respiration, cannot be transmitted, and breathing ceases. Many years before Bernard's experiments, however, Sir Benjamin Brodie* observed that, in animals apparently killed by this poison, the heart continued to beat for a long time; and the idea occurred to him that, if he could keep up respiration for a sufficient length of time, the poison would be eliminated, and the animal completely restored. His first attempts were unsuccessful, but after a little while he succeeded completely; and since then his experiment has been so frequently repeated, that no physiologist can doubt that the complete restoration of an animal poisoned in this way is merely a matter of time, unless the dose has been so overwhelmingly great as to paralyse the heart. I have myself twice restored to life rabbits which a dose of woorara had apparently completely killed, by keeping up artificial respiration in the one case for one, and in the other for four hours; and in foreign laboratories I have seen them partially restored, and only rendered motionless by repeated doses of woorara, oftener than I can well recollect. Hydrocyanic acid is a much more dangerous poison than woorara; for it seems not only to arrest respiration by paralysing the brain, spinal cord, nerves, and muscles, but also to stop the circulation by destroying the power of the heart. The heart, however, is not so soon affected as the respiratory organs; and Brodie succeeded in restoring animals poisoned by small doses of it given in the form of oil of almonds.

The poison of the cobra di capello resembles prussic acid rather than woorara in the universality of its action; for some experiments which I made about a year ago in the laboratory of Dr. Burdon Sanderson seem to show that it paralyses the spinal cord, the motor nerves, and the muscles themselves. The heart also, as Dr. Fayrer and I have found, seems to be paralysed if the dose be very large, as it may be also by an excessive dose of woorara; but it almost always continues to beat for a long time after respiration has ceased. To this fact I have drawn particular attention in my appendix to Dr. Fayrer's admirable work on the *Thanatophidia of India*. The

* *Phil. Trans.*, 1812.

same thing was observed by Fontana (*op. cit.*, tom. i, p. 80) in poisoning by the bite of the viper, and by Weir Mitchell in poisoning by the rattlesnake. Weir Mitchell* found that the heart might be kept pulsating for a long time by means of artificial respiration; but his results do not seem to have been so encouraging as to lead him to propose it as a means of saving life. Dr. Fayrer and I have been more fortunate, and on one occasion we have succeeded in keeping the heart of a rabbit beating for eight hours after the animal was apparently dead. Nor had the heart ceased to pulsate even then; but the hour was late, the room was cold, the assistant was no doubt tired, and the experiment was consequently given up. Although respiration had been continued for a much longer time than is usually necessary with woorara, the animal gave no signs of returning sensibility. This seems to indicate a difference between the poisons. On the probable cause of this, I shall have something to say in a later part of this paper.

The service which artificial respiration renders in cases where breathing has ceased in consequence of asphyxia, whether due to drowning, strangling, or poisoning by carbolic acid in brewers' vats or close rooms, is so generally recognised, that it is unnecessary to say anything about it here. Its use in poisoning by strychnia is not so well known, and, so far as I am aware, has only been tested upon animals. Before I proceed to speak of this, it may be well to say a few words in explanation of the term apnœa, which I shall have to use, as it is employed by physiologists in a different sense from that which is attached to it by many physicians. On the meaning of dyspnœa, both physicians and physiologists are agreed; and both apply it to the violent respiratory efforts which occur when the blood is imperfectly aërated. Apnœa, however, is not unfrequently used by physicians in the sense of extreme dyspnœa, where there is excessive difficulty of respiration. Physiologists apply it to a very different condition—viz., that in which the blood is so excessively aërated that there is no need for breathing at all. This will be much better understood by the reader if he will try a simple experiment on himself. Let him note how many seconds he can hold his breath, and he will find that he can only do so for a very short time. Let him then quickly take several deep breaths, and repeat the experiment. He will now notice that for several seconds more than on the first trial he does not feel any inclination to breathe at all. This is the state of apnœa as understood by physiologists. A few

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* *Researches on the Venom of the Rattlesnake*, 1861, p. 81.

years ago, Rosenthal and Leube* discovered that, when rabbits were kept in this condition by means of artificial respiration, a fatal dose of strychnia might be injected subcutaneously without producing any effect. When the respiration was discontinued, and the animal was allowed to pass from the state of apnœa, convulsions came on even after the respiration had been kept up for as much as three hours. If it were continued for three and a half or four hours, however, the strychnia seemed to have been destroyed or excreted, and respiration might be discontinued without the occurrence of any convulsion whatever. That the lives of the animals had really been saved by artificial respiration, was shown by the fact that they died when a similar dose of strychnia was given to them some time afterwards, and respiration was not used. A year afterwards, another of Rosenthal's pupils—Uspensky—showed† that strychnia was not the only poison the action of which could be prevented by artificial respiration. The convulsive action of brucia, thebaia, and caffeine was abolished in an exactly similar manner; but no influence could be observed upon that of picrotoxin and nicotia.

The examples already given are sufficient to prove that life may often be preserved by means of artificial respiration alone, both in injury and in poisoning. If a man be found lying insensible in a close room, poisoned by the fumes of a charcoal fire, he can generally be restored by respiration if his heart be still beating. But this is not always the case; for the charcoal-fumes contain carbonic oxide, which unites with the colouring matter of the blood, and prevents it from taking up oxygen; so that it may pass time after time through the lungs, and yet remain venous. It is true, that after a while the carbonic oxide will be expelled from the blood, which then will become capable of taking up oxygen as usual; but the heart may stop, and all hope of recovery be lost before this can be effected, if the blood have been much changed by the deadly gas. In such cases, the only hope lies in removing the poisoned blood, and replacing it by healthy.

This does not by any means always succeed; but occasionally the recovery from impending death is almost miraculous, as in a case where it was employed by Dr. Hueter (*Berlin. Klin. Wochensch.*, 1870, p. 341). The patient, who was a strong young man, was living in a hotel, and one night had a fire lighted in the stove of his room. Next morning, he was found perfectly unconscious; his iris and cornea

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* Reichert and Du Bois Reymond's *Archiv*, 1867, p. 629.

† *Op. cit.*, 1868, p. 522.

quite insensible, and his pulse small and rapid. His respiration was weak and intermitting. Just as everything was ready, and transfusion of blood was begun, it failed altogether. Notwithstanding this, fresh blood was allowed to stream into the patient's radial artery; the poisoned blood was drawn from a vein; and respiration was kept up artificially. Gradually the pulse became stronger, spontaneous respiratory movements again began, and the cornea became sensitive. In about five hours, consciousness returned; and in a few days, health was completely restored. Excepting the veritable resurrection of which Legallois speaks, what can be more wonderful than the recovery from impending death just related? And, if the joint use of artificial respiration and transfusion is so successful in one case of poisoning, there seems to be no reason why it should not be so in all. In strychnia-poisoning, for instance, where the quantity absorbed has been too great, and death is impending, notwithstanding the use either of chloroform or of artificial respiration, part of the poison might be removed by abstracting some of the blood in which it was circulating, and fresh blood supplied. If convulsions were occurring constantly, transfusion would be nearly impossible, but they might be stopped either by much chloroform or by woorara. I have already mentioned that woorara is excreted rather quickly by the kidneys; and, consequently, artificial respiration for a few hours is usually sufficient to restore animals which have been poisoned by it.

Let us suppose it, however, to be slowly excreted. Many hours or even days might then elapse before the whole of it could be got rid of; and the maintenance of artificial respiration for such a length of time might be impossible. In such a case as this, the obvious plan of treatment would be, of course, to remove the poison along with the blood in which it was circulating, instead of waiting for its slow removal by the emunctories.

Now it appears to me that this is the case in poisoning by the bites of snakes and this the treatment which must be adopted. We must combine artificial respiration with transfusion. The experiments of Dr. Fayrer show that the poison of the cobra is circulating in the blood of an animal which has been bitten by it; for this blood will kill another animal when injected into it. From those of Fontana, it would seem that the poison of the viper is eliminated from the body; for pigeons did not die if a ligature were placed on the bitten limb above the place where the wound had been inflicted, and removed after some time. Fontana thought that the poison had been destroyed in

the limb, but was evidently puzzled about it, for some of his other experiments had shown him that mixing it with blood did not destroy its virulence. He imagined that he had completely stopped the circulation in the injured limb; but it is more probable that he had only partially done so, and that the poison was thus slowly absorbed from the limb, and, being excreted equally quickly, did the creature no harm. If this explanation of his experiments be not correct, it is difficult to understand why poisoning did not occur when the ligature was removed, as Waterton found to be the case in some similar experiments which he had tried with woorara. So long as the ligature was tight, the woorara remained confined to the limb; but as soon as the circulation was allowed to go on, the poison was absorbed, and the animal died. This may seem to be in direct contradiction to what I have already said regarding the probable comparative slowness of the excretion of snake-poison to that of woorara; but it must be observed that Fontana waited a much longer time before he untied the ligatures than Waterton did, and would thus allow a much larger proportion of the poison to be excreted. It must be noted also that the poison with which he experimented was that of the viper and not of the cobra, and there may be considerable differences in the facility with which they are excreted. It is, however, possible that I am mistaken in supposing that cobra-poison is more slowly excreted than woorara, as the facts on which I base the supposition are simply, that the poison of the cobra, introduced into the stomach, seems to produce death more readily than woorara would do; and that animals poisoned by it may be kept alive for a longer time by artificial respiration without ultimately recovering. The poison of the viper, on the other hand, according to Fontana, may be swallowed, in moderate quantity at least, with impunity, though it also occasionally kills when taken in this manner, as woorara likewise does when the quantity is great and the stomach empty, so that absorption is rapid.

Enough has now been said to show the possible use of transfusion, combined with artificial respiration, not only in poisoning by carbonic oxide, but by strychnia and other poisons. Its employment in collapse from hæmorrhage requires no remarks at present. But, in order to make such a method serviceable, it must be easily performed, and a supply of blood easily got. Now I believe that a very simple apparatus indeed will serve the purpose of transfusing defibrinated blood. But how is a sufficient supply to be got? for it is evident that a considerable quantity may be required. The requisite quantity of human blood in

most cases can hardly be obtained; but it has been experimentally shown that the blood of lambs and calves may be transfused into the blood-vessels of man without doing him any harm.

Two hundred years ago, an objection was raised to this method of proceeding by Laury (*Revue des Deux Mondes*, Jan. 1870, p. 393), who said that, as the blood of a calf or of any other animal whatever is composed of several different particles fitted to nourish the different parts of the body, what is to become of the particles which were destined to produce horns? And, if the blood of a calf be transfused into the veins of a man, as the disposition and habits usually accord with the temperament, will the blood of the calf not give the man the stupidity and brutal inclinations of this animal? Here we almost seem to have Darwin's theory of pangenesis; and, if this theory be true, are not Laury's objections well founded? As far as man is concerned, it may be difficult to give a positive answer either in the affirmative or the negative; but the experiments which Mr. Galton has made on rabbits, for the express purpose of testing Darwin's theory, show that in these animals transfusion has no effect either on the animals themselves or on their progeny. We may therefore, I think, safely conclude that the risk of injuring a man's character, or that of his descendants, by transfusion of an animal's blood, is not for an instant to be weighed in the balance against the chance of saving his life in those cases where alone the operation would be performed.